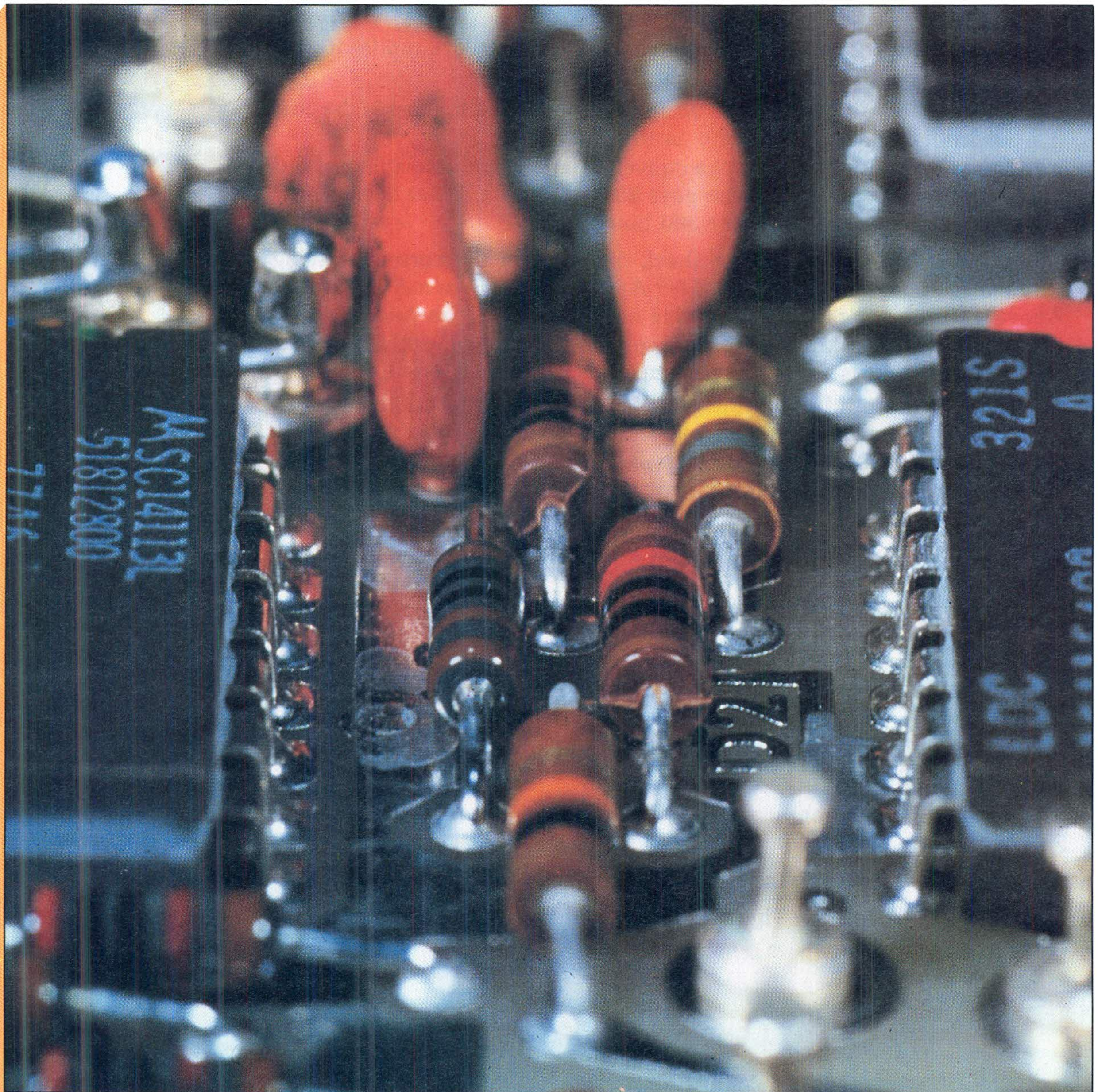


How resistors are connected into an electric circuit determines the total resistance in a circuit. How electronic devices, which are part of the total circuit, are connected also determines the way the system will function. What components of this computer circuit do you recognize? What are the advantages of connecting the resistors in series? In parallel?

Chapter 24

Series and Parallel Circuits

The electric circuits introduced in the last chapter had one source of electric energy and one device that used energy. Often many devices must be connected to one source. In this chapter, you will explore the ways in which devices can be connected in electric circuits.

Goal: You will gain understanding of series and parallel circuits and their applications.

An electric circuit in which all of the current travels through each device is called a series circuit. A parallel circuit allows the current to split and travel through several devices at once. A closer look will show how these circuits work and how they can be used.

24:1 Series Circuits

When resistors are connected in series, all current travels through each resistor, one after the other. Figure 24-1 shows a series circuit. The electric current in the circuit passes through each lamp (resistance) in succession. The current through each resistance is the same. The current flowing in a series circuit is the same everywhere along the wire. To determine the current in the circuit, the effective resistance of the circuit must be found. The **effective resistance** is the resistance of a single resistor that could replace all the resistors in the circuit. The single resistor would have the same current through it as the resistors it replaced. To find the effective resistance, Ohm's law is applied to the circuit as a whole and to its parts. The total voltage drop across the three resistors is equal to the potential difference across the generator, 120 V. The total voltage drop across the three resistors is also equal to the sum of the voltage drops across the individual resistors. That is,

$$V = V_1 + V_2 + V_3.$$

In a series circuit, the current is the same at all points along the wire.

An effective resistance is the resistance cf a single resistor that could replace all the resistors in a circuit.

In a series circuit, the sum of the voltage drops equal the voltage drop across the entire circuit.

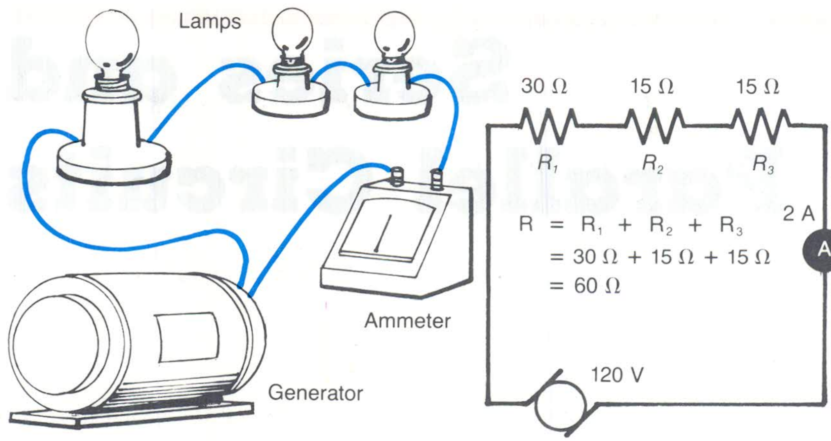


FIGURE 24-1. A series circuit can be represented both pictorially and schematically. The total resistance of a series circuit is equal to the sum of the individual resistances.

According to Ohm's law, the voltage drop across R_1 is given by $V_1 = IR_1$, where I is the current through the circuit. Therefore,

$$V = IR_1 + IR_2 + IR_3$$

$$V = I(R_1 + R_2 + R_3)$$

If the three resistors were replaced by a single resistor with resistance R, the voltage drop across R could be found using Ohm's law: $V = IR$. Comparing this equation with the one above shows that in a series circuit

$$\boxed{R = R_1 + R_2 + R_3.}$$

The effective resistance in a series circuit is the sum of the individual resistances.

The effective resistance, R, of resistors in series is the sum of the resistances. Note that the resistance of R is larger than that of any one of the resistors.

The current through a series circuit is found by calculating the effective resistance R, and then using Ohm's law in the form of $I = V/R$.

EXAMPLE

Current in a Series Circuit

Four 15-Ω resistors are connected in series to a 30-V battery. What is the current in the circuit?

$$R = R_1 + R_2 + R_3 + R_4$$

$$= 15\ \Omega + 15\ \Omega + 15\ \Omega + 15\ \Omega = 60\ \Omega$$

Then apply Ohm's law to the circuit.

$$I = \frac{V}{R} = \frac{30\ \text{V}}{60\ \Omega} = 0.5\ \text{A}$$

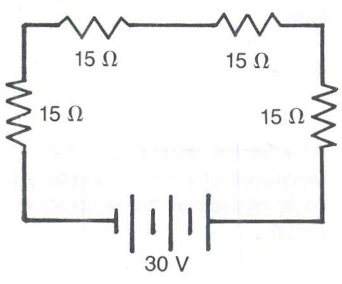


FIGURE 24-2. Use with the Example.

Problems

1. Three 20-Ω resistors are connected in series across a 120-V generator.

1. a. 60 Ω
   b. 2 A

a. What is the effective resistance of the circuit?
b. What is the current in the circuit?

2. A 10-Ω resistor, a 15-Ω resistor, and a 5-Ω resistor are connected in series across a 90-V battery.
   a. What is the effective resistance of the circuit?
   b. What is the current in the circuit?
3. Ten Christmas tree bulbs connected in series have equal resistances. When connected to a 120-V outlet, the current through the bulbs is 0.6 A.
   a. What is the effective resistance of the circuit?
   b. What is the resistance of each bulb?

3. a. 200 Ω
   b. 20 Ω

4. A lamp having a resistance of 10 Ω is connected across a 15-V battery.
   a. What is the current through the lamp?
   b. What resistance must be connected in series with the lamp to reduce the current to 0.5 A?

24:2 Voltage Drops in a Series Circuit

The voltage drop across a device in a series circuit can be calculated by Ohm's law: $V = IR$. First find the effective resistance of the circuit. Next use the effective resistance to find the current, I. Then multiply I by the resistance of the device to find the voltage drop.

EXAMPLE

Voltage Drops in a Series Circuit

A 5.0-Ω resistor and a 10.0-Ω resistor are connected in series and placed across a 45.0-V potential difference.

a. What is the effective resistance of the circuit?
b. What is the current through the circuit?
c. What is the voltage drop across each resistor?
d. What is the total voltage drop across the circuit?

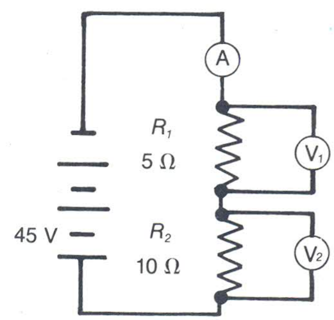


FIGURE 24-3. Use with the Example.

Given: $R_1 = 5.0\ \Omega$, $R_2 = 10.0\ \Omega$, $V = 45.0\ V$

Unknowns: R, I, V_1, V_2

Basic equation: $V = IR$

Solution:

a. $R = R_1 + R_2$
$= 5.0\ \Omega + 10.0\ \Omega = 15.0\ \Omega$

b. $I = \frac{V}{R} = \frac{45.0\ V}{15.0\ \Omega} = 3.00\ A$

c. The voltage drop across R_1 is
$V_1 = IR_1 = (3.00\ A)(5.0\ \Omega) = 15\ V$

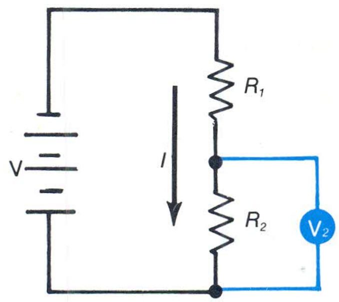


FIGURE 24-4. Use with the Example.

The voltage drop across R_2 is

$$V_2 = IR_2$$
$$= (3.00\ \text{A})(10.0\ \Omega) = 30.0\ \text{V}$$

d. $V = V_1 + V_2$
$$= 15\ \text{V} + 30.0\ \text{V} = 45\ \text{V}$$

An important application of series resistors is the voltage divider. The voltage divider is designed to obtain a desired voltage from a battery that supplies a larger voltage. Consider the circuit in Figure 24-4. Two resistors, R_1 and R_2, are connected in series across a battery of voltage V. The effective resistance of the circuit is $R = R_1 + R_2$. The current, I, is given by $I = V/R = V/(R_1 + R_2)$. The desired voltage, V_2, is the voltage drop across resistor R_2. According to Ohm's law, V_2 equals IR_2. Replacing I by its equivalent calculated by the equation above gives

$$V_2 = IR_2 = \left(\frac{V}{R_1 + R_2}\right) \cdot R_2 = \frac{VR_2}{R_1 + R_2}$$

A voltage divider is a pair of resistors used to obtain a desired voltage from a battery that supplies a higher voltage.

EXAMPLE

Voltage Divider

A 9.0-V battery and two resistors, $R_1 = 400\ \Omega$ and $R_2 = 500\ \Omega$, are connected as a voltage divider. What is the voltage across R_2?

Given: $V = 9.0\ \text{V}$, $R_1 = 400\ \Omega$, $R_2 = 500\ \Omega$

Unknown: V_2

Basic equation: $V_2 = \dfrac{VR_2}{R_1 + R_2}$

Solution:

$$V_2 = \frac{VR_2}{R_1 + R_2} = \frac{(9\ \text{V})(500\ \Omega)}{400\ \Omega + 500\ \Omega} = 5\ \text{V}$$

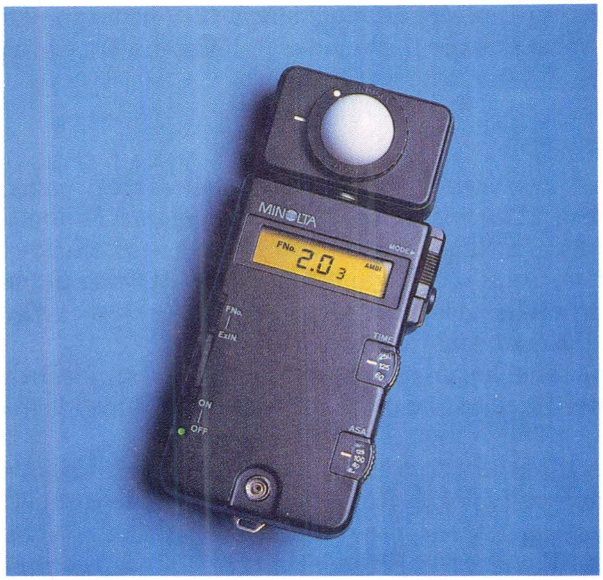
A photoresistor is a device whose resistance is changed by light striking it. Photoresistors are made of semiconductors like selenium or cadmium sulfide. A typical photoresistor can have a resistance of 400 Ω when light strikes it but 400 000 Ω when in the dark. When a photoresistor is used in a voltage divider, the output voltage across the photoresistor is determined by the amount of light striking the photoresistor. This circuit can be used as a light meter or "electric eye." Examples include automatic door openers and burglar alarms.

Problems

5. A 20.0-Ω resistor and a 30.0-Ω resistor are connected in series and placed across a 110-V potential difference.

a. What is the effective resistance of the circuit?
b. What is the current in the circuit?
c. What is the voltage drop across each resistor?
d. What is the total voltage drop across the circuit?

5. a. 50.0 Ω
b. 2.2 A
c. 44 V, 66 V
d. 110 V



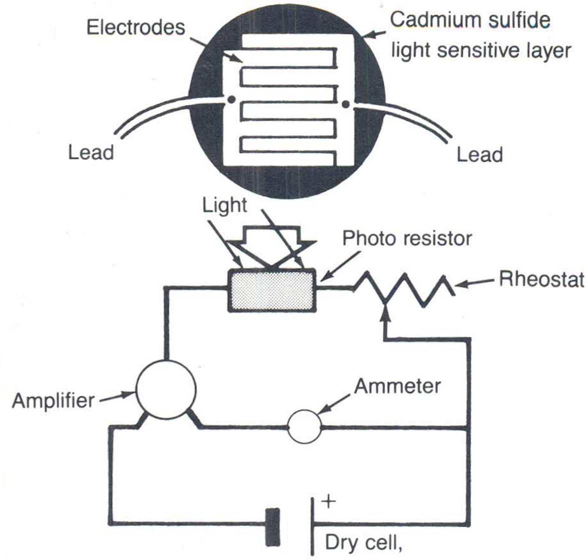


FIGURE 24-5. A lightmeter (a) and schematic diagram (b).

6. Three 30.0-Ω resistors are connected in series and placed across a difference in potential of 135 V.
   a. What is the effective resistance of the circuit?
   b. What is the current in the circuit?
   c. How much voltage is dropped across each resistance?
   d. What is the total voltage drop across all three resistors?
7. Three resistors of 3.0 Ω, 5.0 Ω, and 4.0 Ω are connected in series across a 12-V battery.
   a. What is the effective resistance of the three resistors?
   b. What is the current in the circuit?
   c. What is the voltage drop across each resistor?
   d. What is the total voltage drop across the circuit?

7. a. 12 Ω
   b. 1.0 A
   c. 3.0 V, 5.0 V, 4.0 V
   d. 12 V

8. A 10.0-Ω resistor and a variable resistor are connected in series and placed across a 12-V source. The variable resistor is adjusted until the current in the circuit is 0.6 A.
   a. At what resistance is the variable resistor set?
   b. What are the voltage drops across the resistor and across the variable resistor?
9. In a voltage divider with $V = 9.0$ V, $R_1 = 500$ Ω and R_2 is a photoresistor.
   a. What is the output voltage, V_2, across R_2 when a bright light strikes the photocell and $R_2 = 4.0 \times 10^2$ Ω
   b. When the light is dim, $R_2 = 4.0 \times 10^3$ Ω. What is V_2?
   c. When the photoresistor is in the dark, $R_2 = 4.0 \times 10^5$ Ω. What is V_2?

9. a. 4 V
   b. 8 V
   c. 8 V

10. A student is designing a voltage divider using a 12-V battery and a 100.0-Ω resistor. What must be the value of R_2 if the student wants an output voltage of 4.0 V across it?

24:3 Parallel Circuits

In a parallel circuit, each resistor provides a new path for electrons to flow.

In a parallel circuit, the current can flow through several paths. Consider rapids in a river. The water can divide into several channels. Some channels may have a large flow of water, some a small flow. However, the sum of the flows is equal to the total flow of water in the river. By analogy, in a parallel electrical circuit, the total current is the sum of the currents through each resistor.

The water drops the same height as it flows through the rapids. In a parallel circuit, the electric potential difference across each path is the same.

Figure 24-6 shows three resistors connected in parallel across a 120-V potential difference. Each line from *A* to *B* is a complete circuit across the generator and operates as if the other lines were not present. A 60-Ω resistor across a difference in potential of 120 V allows a current of 2 A to flow.

$$I = \frac{V}{R} = \frac{120\ \text{V}}{60\ \Omega} = 2\ \text{A}$$

Each 60-Ω resistor in Figure 24-6 allows 2 A of current to flow between points *A* and *B*. Thus, the total current between the two points is 6 A. The potential difference across each resistor is 120 V. Ohm's law shows the circuit as a whole has a resistance of only 20 Ω. The effective resistance of a parallel circuit is the resistance of a single resistor that could replace all the parallel resistors in the circuit.

$$R = \frac{V}{I} = \frac{120\ \text{V}}{6\ \text{A}} = 20\ \Omega$$

Placing resistors in parallel always decreases the effective resistance of

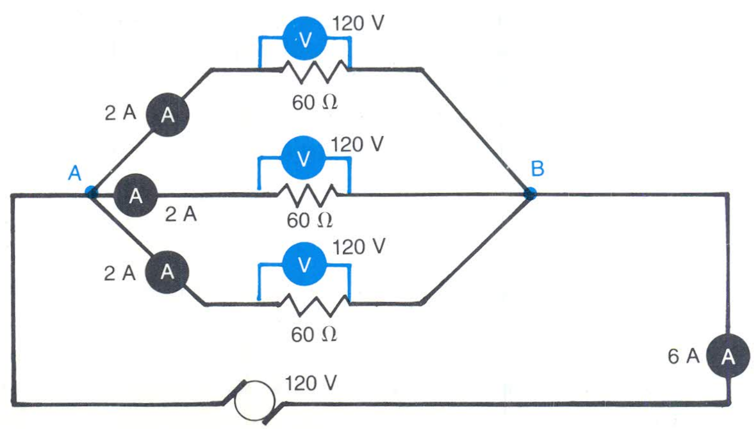


FIGURE 24-6. In a parallel circuit, the reciprocal of the total resistance is equal to the sum of the reciprocals of the individual resistances. Here you see three 60-ohm resistors connected in parallel. For each resistor, the voltage drop is 120 volts and the current is 2 amperes.

the circuit. The effective resistance decreases because each new resistor provides an additional path for the electrons to follow between points A and B. Notice that the effective resistance of the circuit is less than the resistance of any single resistor in the circuit. The effective resistance of a parallel circuit can be found by using the fact that total current in the circuit is the sum of the currents through the branches of the circuit. If I is the total current, and I_1, I_2, and I_3 are the currents through each of the branches, then

The total resistance of a parallel circuit decreases as each new resistor is added.

Total current in a parallel circuit is the sum of the currents in its branches.

$$I = I_1 + I_2 + I_3$$

The current through R_1 can be calculated using $I_1 = V/R_1$. The total current through the effective resistance R of the circuit is given by $I = V/R$. All voltage drops in a parallel circuit are the same. Therefore, the above equation for the current becomes

The voltage drop across each branch is equal to the voltage of the source.

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Dividing both sides of the equation by V gives

$$\boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

The effective resistance of the circuit shown in Figure 24-5 is thus

$$\frac{1}{R} = \frac{1}{60\ \Omega} + \frac{1}{60\ \Omega} + \frac{1}{60\ \Omega} = \frac{3}{60\ \Omega} = \frac{1}{20\ \Omega}$$

$$R = 20\ \Omega$$

EXAMPLE

Total Resistance and Current in a Parallel Circuit

Three resistors of 60.0 Ω, 30.0 Ω, and 20.0 Ω are connected in parallel across a 90.0-V difference in potential, Figure 24-7.

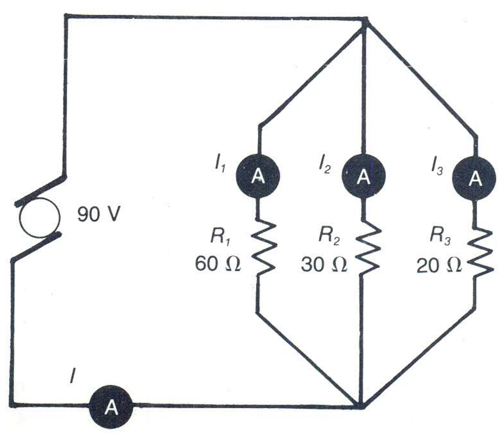
a. Find the effective resistance of the circuit.
b. Find the current in the entire circuit.
c. Find the current through each branch of the circuit.

Given: $R_1 = 60.0\ \Omega$, $R_2 = 30.0\ \Omega$, $R_3 = 20.0\ \Omega$, $V = 90.0\ \text{V}$

Unknowns: R, I, I_1, I_2, I_3

Basic equation: $V = IR$

FIGURE 24-7. Use with the Example.



Solution:

a. $$\frac{1}{R} = \frac{1}{60.0\ \Omega} + \frac{1}{30.0\ \Omega} + \frac{1}{20.0\ \Omega}$$

$$\frac{1}{R} = \frac{6}{60.0\ \Omega}$$

$$R = 10.0\ \Omega$$

b. $I = \frac{V}{R} = \frac{90.0\ V}{10.0\ \Omega} = 9.00\ A$

c. The voltage drop across each resistor is 90.0 V.

$$(\text{for } R_1)\ I_1 = \frac{V}{R_1} = \frac{90.0\ V}{60.0\ \Omega} = 1.50\ A$$

$$(\text{for } R_2)\ I_2 = \frac{V}{R_2} = \frac{90.0\ V}{30.0\ \Omega} = 3.00\ A$$

$$(\text{for } R_3)\ I_3 = \frac{V}{R_3} = \frac{90.0\ V}{20.0\ \Omega} = 4.50\ A$$

The largest current flows through the smallest resistor. The sum of the current in the lines is 9.00 A as shown in Part *b*. Dividing the voltage by the sum of the currents yields the effective resistance of the circuit. The solution is the same as was found in Part *a*.

Problems

11. a. 5.00 Ω
b. 6.00 A
c. 2.00 A

13. a. 20.0 Ω
b. 6.00 A
c. 1.00 A, 2.00 A, 3.00 A

15. a. 2.0 A
b. 1.0 A
c. 3.0 A
d. $5.0 \times 10^1\ \Omega$
e. 3.0 A, yes

11. Three 15.0 Ω resistors are connected in parallel and placed across a difference in potential of 30.0 V.
   - **a.** What is the effective resistance of the parallel circuit?
   - **b.** What is the current through the entire circuit?
   - **c.** What is the current through each branch of the circuit?

12. Two 10.0-Ω resistors are connected in parallel and placed across the terminals of a 15-V battery.
   - **a.** What is the effective resistance of the parallel circuit?
   - **b.** What is the total current in the circuit?
   - **c.** What is the current through each branch of the circuit?

13. A 120.0-Ω resistor, a 60.0-Ω resistor, and a 40.0-Ω resistor are connected in parallel and placed across a potential difference of 120.0 V.
   - **a.** What is the effective resistance of the parallel circuit?
   - **b.** What is the current in the entire circuit?
   - **c.** What is the current through each branch of the circuit?

14. A 6.0-Ω resistor, an 18-Ω resistor, and a 90.0-Ω resistor are connected in parallel and placed across a 36-V potential difference.
   - **a.** What is the current through each resistor?
   - **b.** What is the total current in the circuit?
   - **c.** What is the effective resistance of the circuit?

15. A 75-Ω heater and a 150-Ω lamp are connected in parallel across a potential difference of 150 V.
   - **a.** What is the current through the 75-Ω heater?
   - **b.** What is the current through the 150-Ω lamp?
   - **c.** What is the current through the entire circuit?

d. What is the effective resistance of the entire circuit?
e. Divide the voltage by the effective resistance. Does the result agree with the solution to Part **c**?

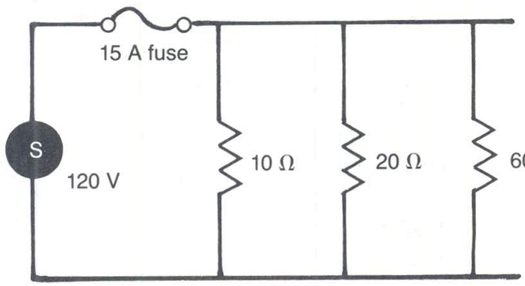


FIGURE 24-8. A 60 Ω, a 20 Ω, and a 10 Ω resistor are connected in parallel across a 120-V source. The current through the circuit will cause the fuse to melt.

24:4 Applications of Parallel Circuits

In a parallel circuit, each resistor can be operated independently.

Figure 24-8 shows resistors of 60 Ω, 20 Ω, and 10 Ω connected in parallel across a 120-V source. The circuit also contains a 15-A fuse in series with the resistors. The effective resistance of the circuit is

$$\frac{1}{R} = \frac{1}{60\ \Omega} + \frac{1}{20\ \Omega} + \frac{1}{10\ \Omega} = \frac{10}{60\ \Omega}$$

$$R = 6\ \Omega$$

The current flowing through the lines is

$$I = \frac{V}{R} = \frac{120\ \text{V}}{6\ \Omega} = 20\ \text{A}$$

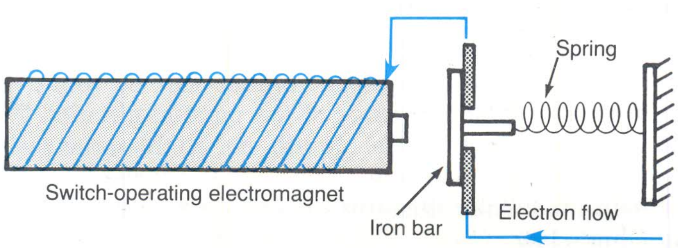
Notice that 20 A exceeds the capacity of the 15-A fuse. This will cause the fuse to melt, or "blow," cutting off current to the entire circuit.

Fuses and circuit breakers are safety devices that prevent too much current from flowing in a circuit.

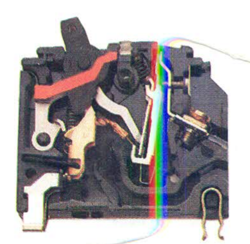
Fuses and circuit breakers are switches in the line that act as safety devices. They prevent circuit overloads that can occur when too many appliances are turned on at the same time. When appliances are connected in parallel, each additional appliance placed in operation reduces the effective resistance in the circuit and causes more current to flow through the wires. The additional current may produce enough thermal energy (I^2R) to melt the insulation on wires, causing a short circuit.

FIGURE 24-9. When the current in a circuit is too great, the metal bar in this circuit breaker is pulled away from its contact points. The current stops flowing.

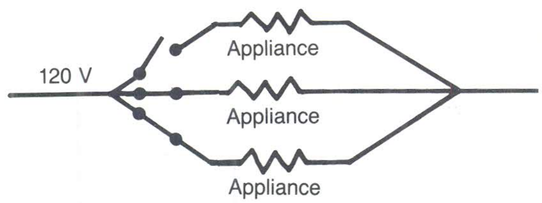
a



b



a



b

FIGURE 24-10. The wiring arrangement in this house (a) will permit the use of one or more appliances at the same time. This wiring diagram (b) indicates the parallel nature of the circuit.

A fuse is a short piece of metal that melts when the heating effect of the current reaches a set magnitude. A circuit breaker is an automatic switch that opens when the current reaches some set value. If an overload occurred in the circuit shown in Figure 24-9, the fuse would melt. Then no current would flow anywhere in the circuit. Usually, a house is wired with several separate parallel circuits located in different parts of the house. Such an arrangement tends to prevent an overload in any single circuit.

A short circuit occurs when a new circuit containing a very low resistance is accidentally formed. The current in this circuit becomes very large. This large current could start a fire if there were no fuse or circuit breaker in the circuit. For example, if a lamp cord becomes frayed, its input and return wires could accidentally be brought together. A piece of copper wire in the lamp cord might have a resistance of only 0.010 Ω. When placed across 120 V, this resistance would cause a current of

$$\frac{120\ \text{V}}{0.010\ \Omega} = \text{ or } 12\,000\ \text{A}$$

The fuse or circuit breaker reacts immediately to the increase in current and breaks the circuit. Thus, the wire is prevented from becoming hot and starting a fire.

FIGURE 24-11. The metal wire in a fuse melts when the circuit is overloaded. The fuse must then be replaced.

24:5 Series-Parallel Circuits

Often a circuit consists of a combination of series and parallel circuits. The current in a complex circuit can be found by first calculating the effective resistance of the parallel circuits. Then the effective resistance of the parallel circuits and all the series resistances can be combined into one total effective resistance, and the total current determined. The voltage drop across each resistor can be found by using Ohm's law.

EXAMPLE

Series-Parallel Circuit

In Figure 24-12, a 30.0-Ω resistor is connected in parallel with a 20.0-Ω resistor. The parallel connection is placed in series with an 8.0-Ω resistor, and the entire circuit is placed across a 60.0-V difference of potential.

a. What is the effective resistance of the parallel portion of the circuit?
b. What is the effective resistance of the entire circuit?
c. What is the current in the entire circuit?
d. What is the voltage drop across the 8.0-Ω resistor?
e. What is the voltage drop across the parallel portion of the circuit?
f. What is the current in each line of the parallel portion of the circuit?

Solution:

a. R_2 and R_3 are connected in parallel. Their effective resistance is

$$\frac{1}{R_{2,3}} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{30.0\ \Omega} + \frac{1}{20.0\ \Omega} = \frac{5}{60.0\ \Omega}$$

$$R_{2,3} = 12.0\ \Omega$$

In analyzing series-parallel circuits, first combine parallel resistors. Then combine series resistors.

b. The circuit is equivalent to a series circuit with an 8.0-Ω resistor and a 12.0-Ω resistor in series, Figure 25-13.

$$R = R_1 + R_{2,3}$$

$$= 8.0\ \Omega + 12.0\ \Omega = 20.0\ \Omega$$

c. The current in the circuit is

$$I = \frac{V}{R}$$

$$= \frac{60.0\ \text{V}}{20.0\ \Omega} = 3.00\ \text{A}$$

Ohm's law can be used on each separate part of a series-parallel circuit.

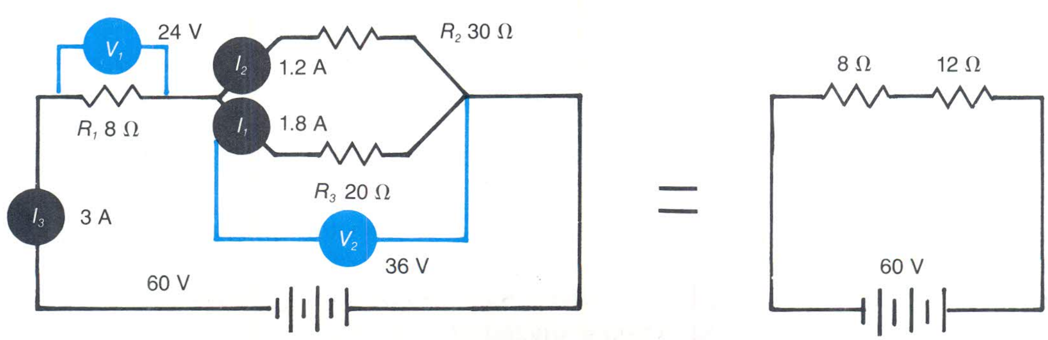


FIGURE 24-12. Use with the Example.

d. The voltage drop across the 8-Ω resistor is

$$V_1 = IR_1$$
$$= (3.00\ \text{A})(12.0\ \Omega) = 24.0\ \text{V}$$

e. The parallel branch (R_2 and R_3) behaves as a 12.0-Ω resistor. Therefore, the voltage drop across it is

$$V_p = IR_{2,3}$$
$$= (3.00\ \text{A})(12.0\ \Omega) = 36.0\ \text{V}$$

f. The 36.0-V drop across the parallel portion of the circuit is the same across all parts of the parallel circuit. Therefore, the current through the 30.0-Ω resistor is

$$I_2 = \frac{V}{R_2}$$
$$= \frac{36.0\ \text{V}}{30.0\ \Omega} = 1.20\ \text{A}$$

The current through the 20.0-Ω resistor is

$$I_3 = \frac{V}{R_3}$$
$$= \frac{36.0\ \text{V}}{20.0\ \Omega} = 1.80\ \text{A}$$

The current through the parallel part of the circuit is

$$1.20\ \text{A} + 1.80\ \text{A, or } 3.00\ \text{A}$$

This value agrees with the value for current calculated in Part c.

Problems

16. Two 60-Ω resistors are connected in parallel. This parallel arrangement is connected in series with a 30-Ω resistor. The entire circuit is then placed across a 120-V potential difference.

- **a.** Draw a diagram of the circuit.
- **b.** What is the effective resistance of the parallel portion of the circuit?
- **c.** What is the effective resistance of the entire circuit?
- **d.** What is the current in the circuit?
- **e.** What is the voltage drop across the 30-Ω resistor?
- **f.** What is the voltage drop across the parallel portion of the circuit?
- **g.** What is the current in each branch of the parallel portion of the circuit?

17. a. "diagram"

17. Three 15-Ω resistors are connected in parallel. This arrangement is connected in series with a 10-Ω resistor. The entire circuit is then placed across a 45-V difference in potential.

- **a.** Draw a diagram of the circuit.

b. What is the effective resistance of the parallel portion of the circuit?
c. What is the effective resistance of the entire circuit?
d. What is the current in the entire circuit?
e. What is the voltage drop across the 10-Ω resistor.
f. What is the voltage drop across the parallel portion of the circuit?
g. What is the current in each branch of the parallel portion of the circuit?

b. 5.0 Ω
c. 15 Ω
d. 3.0 A
e. 30 V
f. 15 V
g. 1.0 A

18. Three 15-Ω resistors are connected in parallel. They are connected in series to a second set of three 15-Ω resistors, also connected in parallel. The entire circuit is then placed across the terminals of a 12-V battery.

a. What is the effective resistance of the circuit?
b. What is the circuit current?
c. What is the current through each resistor?

24:6 Ammeters and Voltmeters

An **ammeter** is used to measure the current in a circuit. An ammeter is placed in a circuit in series with the resistors. The resistance of an ammeter must be very low. A high resistance increases the effective resistance of the circuit; an increased resistance causes a reduced current. Thus, an ammeter with a high resistance would change the value of the current the meter was used to measure.

An ammeter measures current in a circuit.

An ammeter should have as low a resistance as possible.

FIGURE 24-13. A multi-meter can be used to measure currents and voltage drops in electric circuits.

A voltmeter measures voltage drop across a circuit.

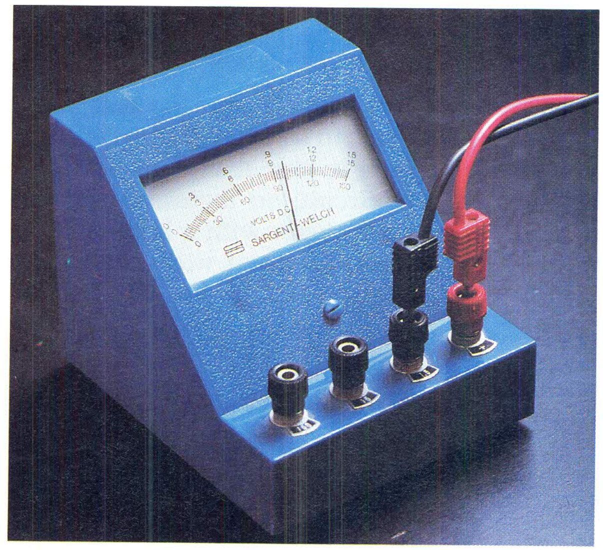
A voltmeter should have as high a resistance as possible.

A **voltmeter** is used to measure the voltage drop across an entire circuit or a part of a circuit. A voltmeter is placed in parallel with the part of a circuit across which the voltage drop is to be measured. A voltmeter must have a very high resistance so that the current through it is very small. Consider the circuit shown in Figure 24-14d. It is important to remember that the voltage drop across the entire circuit remains constant. The effective resistance of the branch containing R_2 and a low-resistance voltmeter would be less than R_2 alone. Therefore, the effective resistance of the entire circuit would also be decreased and the current in the circuit would increase. This increased current would cause a larger voltage drop across R_1, and the voltage drop across the R_2 branch would decrease. Thus, a low-resistance voltmeter would change the value of the voltage it is used to measure. The resistance of a voltmeter is at least 20 000 Ω. Many electronic voltmeters now in use have resistances of 10^7 Ω.

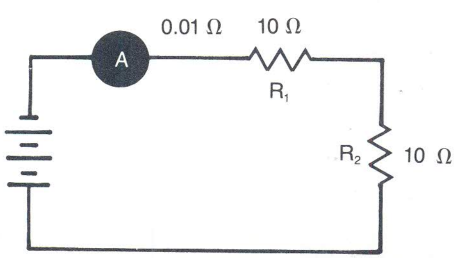
FIGURE 24-24. A battery tester (a) and a standard laboratory voltmeter (b) measure potential differences. Ammeters are always placed in series within a circuit (c) and voltmeters are placed in parallel (d).

a

b

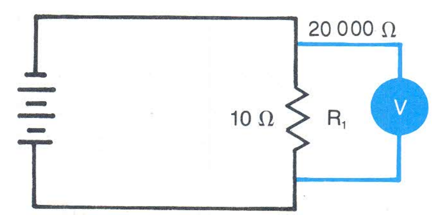


c



$$10\ \Omega + 10\ \Omega + 0.01\ \Omega = 20\ \Omega$$

d



$$\frac{1}{10\ \Omega} + \frac{1}{20\,000\ \Omega} \approx \frac{1}{10\ \Omega}$$

Summary

1. The current is the same everywhere in a series circuit. 24:1
2. The sum of the voltage drops across the resistors in a series circuit is equal to the potential difference across the voltage source. 24:1
3. The effective resistance of a series circuit is the sum of the resistances of its parts. 24:1
4. A voltage divider is a series circuit used to provide a potential difference of specific value. 24:2
5. The voltage drops across all branches of a parallel circuit are the same. 24:3
6. In a parallel circuit, the total current is equal to the sum of the currents in the branches. 24:3
7. The reciprocal of the effective resistance of a parallel circuit is equal to the sum of the reciprocals of the individual resistances. 24:3
8. If any branch of a parallel circuit is opened, there is no current in that branch. The current in the other branches is unchanged. 24:4
9. A circuit is often a combination of series and parallel circuits. The parallel circuit is first reduced to a single resistance. Then the series circuit is replaced by a single resistance. 24:5
10. An ammeter is used to measure the current in a circuit or in a part of a circuit. An ammeter is always connected in series. 24:6
11. A voltmeter measures the potential difference (voltage) across any part of a circuit or across the entire circuit. A voltmeter is always connected in parallel. 24:6

Questions

1. Circuit *A* contains three 60-Ω resistors in series. Circuit *B* contains three 60-Ω resistors in parallel. How does the current in the second 60-Ω resistor change if a switch cuts off the current to the first 60-Ω resistor in
   a. circuit *A*?
   b. circuit *B*?
2. Why is there a difference in total resistance between three 60-Ω resistors connected in series and three 60-Ω resistors connected in parallel?

3. An engineer needs a 10-Ω control resistor or a 15-Ω control resistor. But, there are only 30-Ω resistors in stock. Must new resistors be bought? Explain.
4. For each part of this question, write the form that applies: series circuit or parallel circuit.
   a. The current is the same throughout.
   b. The total resistance is equal to the sum of the individual resistances.
   c. The voltage drop is the same across each resistor.
   d. The voltage drop is proportional to the resistance.
   e. Adding a resistor decreases the total resistance.
   f. Adding a resistor increases the total resistance.
   g. If one resistor is turned off or broken, there is no current in the entire circuit.
   h. If one resistor is turned off, the current through all other resistors remains the same.
   i. Suitable for house wiring.
5. Explain the function of a fuse in an electric circuit.
6. What is a short circuit? Why is a short circuit dangerous?
7. Why does an ammeter have a very low resistance?
8. Why does a voltmeter have a very high resistance?

Problems–A

1. Two resistors of 5 Ω and 7 Ω are connected in series across a 12-V battery.
   a. What is the effective resistance of the circuit?
   b. What is the current through the 5-Ω resistor?
   c. What is the current through the 7-Ω resistor?
   d. What is the voltage drop across each resistor?
2. Two 6.0-Ω resistors and a 3.0-Ω resistor are connected in series. A potential difference of 6.0 V is applied to the circuit.
   a. What is the effective resistance of the circuit?
   b. What is the current in the circuit?
   c. What is the voltage drop across each resistor?
3. A light bulb has a resistance of 2.0 Ω. It is connected in series with a variable resistor. A difference in potential of 6.0 V is applied to the circuit. An ammeter indicates that the current of the circuit is 0.50 A. At what resistance is the variable resistor set?
4. What resistance is connected in series with an 8-Ω resistor connected to a 60.0-V generator if the current through the resistors is 4.0 A?

5. Ten Christmas tree lights are connected in series. When they are plugged into a 120-V outlet, the current through the lights is 0.75 A. What is the resistance of each light?

6. A 20-Ω lamp and a 5-Ω lamp are connected in series and placed across a difference in potential of 50 V.
   a. What is the effective resistance of the circuit?
   b. What is the current in the circuit?
   c. What is the voltage drop across each lamp?
   d. What is the power used in each lamp?

7. A 20.0-Ω lamp and a 5.0-Ω lamp are connected in parallel and placed across a difference in potential of 50.0 V.
   a. What is the effective resistance of the circuit?
   b. What is the current in the circuit?
   c. What is the current through each resistor?
   d. What is the voltage drop across each resistor?
   e. What is the power used by each lamp?
   f. Compare this result to the result of the preceding problem.

8. A 16.0-Ω and a 20.0-Ω resistor are connected in parallel. A difference in potential of 40.0 V is applied to the combination.
   a. Compute the effective resistance of the parallel circuit.
   b. What is the current in the circuit?
   c. What is the current through the 16.0-Ω resistor?

9. A household circuit contains six 240-Ω lamps (60-W bulbs) and a 10.0-Ω heater. The voltage across the circuit is 120 V.
   a. What is the current in the circuit when four lamps are on?
   b. What is the current when all six lamps are on?
   c. What is the current in the circuit if all six lamps and the heater are operating?

10. Determine the reading of each ammeter and each voltmeter in Figure 24-15.

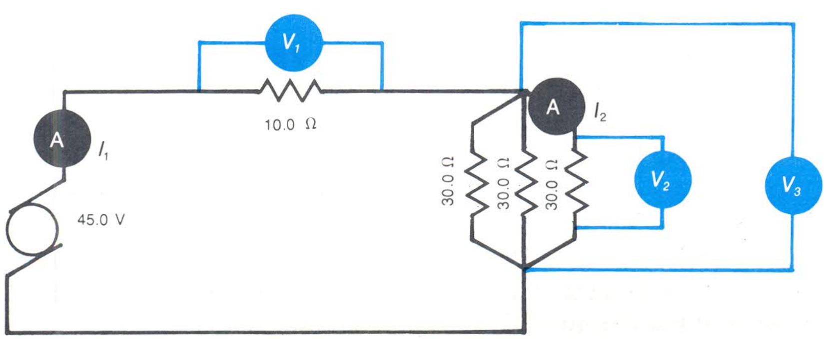


FIGURE 24-15. Use with Problem 10.

11. Find the reading of each ammeter and each voltmeter in Figure 24-16.
12. Determine the power in watts used by each resistance shown in Figure 24-15.

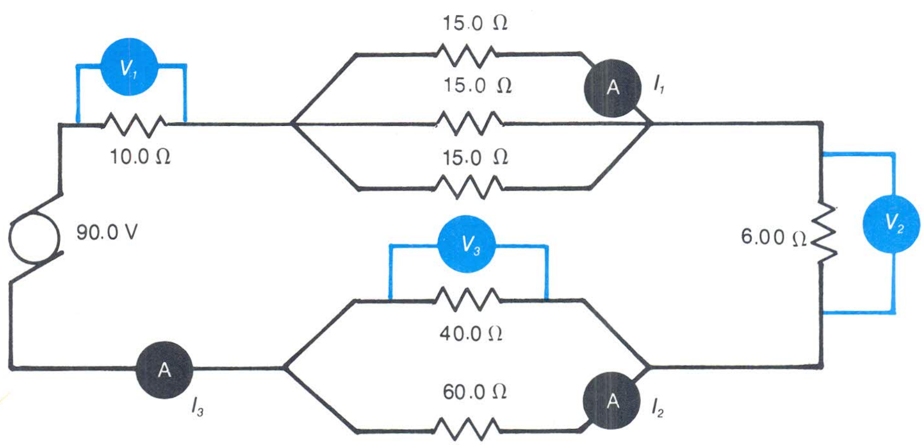


FIGURE 24-16. Use with Problem 11.

Problems–B

1. During a laboratory exercise, you are supplied with the following apparatus:
   - a battery of potential difference V,
   - two heating elements of low resistance that can be placed in water,
   - an ammeter of negligible resistance,
   - a voltmeter of extremely high resistance,
   - wires of negligible resistance,
   - a beaker that is well-insulated and has negligible heat capacity,
   - 100.0 g of water at 25°C.

   a. By means of a diagram using standard symbols, show how these components should be connected to heat the water as rapidly as possible.

   b. If the voltmeter reading holds steady at 50.0 V and the ammeter reading holds steady at 5.0 A, estimate the time in seconds required to completely vaporize the water in the beaker. Use 4.2 J/g · C° as the specific heat of water and 2300 J/g as the heat of vaporization of water.

2. A typical home circuit is diagrammed in Figure 24-17. Note that the lead lines to the kitchen lamp have very low resistances. The lamp contains a typical 60-W incandescent bulb of resistance 240.00-Ω. Although the circuit is a parallel circuit, the lead lines are in series with each of the components of the circuit.

a. Compute the effective resistance of the circuit consisting of just the light and the lead lines to and from the light. We will assume that the power saw and wall outlets are not in use.
b. Show that the current to the bulb is essentially 0.5 amperes and that the bulb is a 60-W device.
c. Since the current in the bulb is 0.5 A, the current in the lead lines must also be 0.5 A. Calculate the voltage drop due to the two leads.

3. A power saw is operated by an electric motor. When electric motors are first turned on, they have very low resistances. In Chapter 26 we will study why the resistance is low. Suppose that the kitchen light discussed in Problem 2 is on and the power saw is suddenly turned on. The saw plus the lead lines between the saw and the light have an initial total resistance of 6.0 Ω.

a. Compute the effective resistance of the light-saw parallel circuit.
b. What current flows through the two leads to the light?
c. What is the total voltage drop across the two leads to the light?
d. What voltage remains to operate the light? Will this voltage cause the light to dim temporarily? (You may have noticed this effect before.)

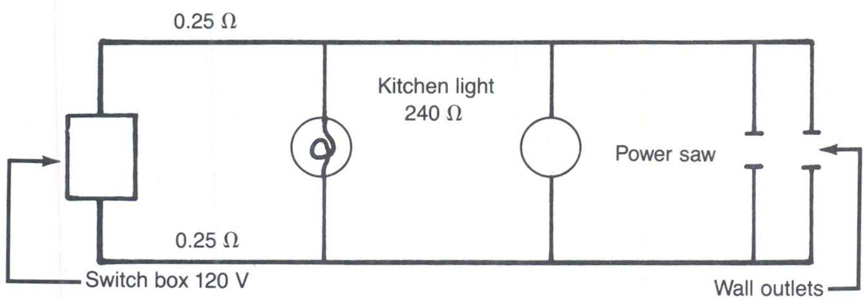


FIGURE 24-17. Use with Problems 2 and 3.

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